



EYE IN THE SKY

Satellites are used for more than just beaming useless TV shows to your living room. Mike Bedford explains how they can produce images of staggering clarity that can pinpoint objects less than a metre wide

In August 1960 an American satellite called Corona slipped secretly into orbit. For the first time it was possible to see what the Earth looked like from space. But only a privileged few were permitted to see these groundbreaking images, for Corona's purpose was to spy on the communist Eastern bloc.

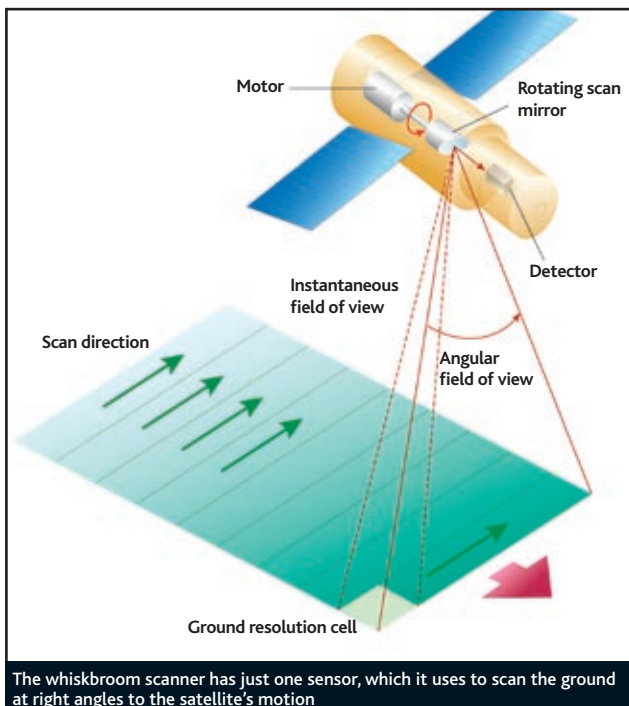
It may have seemed futuristic, but photographing the Earth from orbit didn't rely on computer technology in the 1960s. Instead, images were captured using a conventional camera and the film jettisoned to Earth in a return canister, which was snatched from the air by a US Air Force C-119 aircraft and returned to an Air Force base in Hawaii. Each satellite operated for just a few days before its supply of film ran out. The cost per image was huge: in all just over 100 Corona satellites, costing \$850 million (around £468 million), returned around 800,000 images over a 12-year period.

The world of satellite imaging is very different today. The technology has moved on, the prices are low, and whereas the USA didn't even acknowledge the existence of Corona until 1996, today's imaging satellites are operated commercially and the photographs are available to anyone. What's more, the highest-resolution satellites can reveal objects less than a metre across from their orbits 800km above the Earth's surface. That's like taking a digital photograph of Geneva while you're standing in London and being able to see individual people walking down the street.

SATELLITE SCANNERS

Ordinary photographers started abandoning film only a few years ago, but satellites went digital much earlier. Although it might be a hassle to take your film to the local supermarket for processing, this is nothing compared to the difficulty and expense of returning a film from space for processing. But here the parallel ends. Instead of a digital camera, imaging satellites use a scanner that builds up an image pixel by pixel or line by line, just like the flatbed scanners used to scan a paper document; see our *Labs* on page 174 for details.

The first type of scanner to be used on board satellites was the whiskbroom scanner. It was popular in the early days because it required very few of the photo sensors that were so expensive before charge-coupled devices (CCDs) came along,



multispectral (colour) scanner is similar, as we'll see shortly.

A rotating mirror between the scanner's lens assembly and the single sensor causes the instrument to scan across the path of the satellite, pixel by pixel, building up a single image line at right angles to the satellite's motion. However, because of the satellite's forward motion, each of these scans produces a line slightly ahead of the previous line and so, by continually repeating this process, a two-dimensional image is captured. An additional mirror assembly (not shown in the diagram) corrects for the forward motion of the satellite during the acquisition of a scan line. Without this correction mirror, successive scan lines would form a zigzag pattern rather than being square to the direction of travel.

The alternative is to use a pushbroom scanner, and this is used in the vast majority of today's Earth-imaging satellites. The pushbroom scanner uses a CCD like an ordinary digital camera but, rather than comprising a two-dimensional array of photo-sensitive elements, its CCD contains a single row of thousands of elements. Because it uses a linear array of photo-sensitive elements instead of a single photo sensor, the pushbroom scanner captures an entire line of the image at once.

Therefore, a two-dimensional image is created as a result of the forward motion of the satellite.

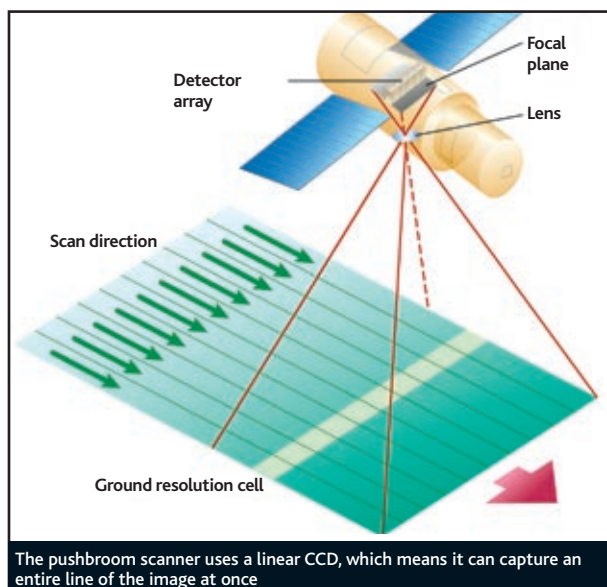
PUSHBROOM SCANNERS

We've seen how scanners on board satellites can produce monochrome images, but what about colour? In fact, most of the scanners on today's imaging satellites aren't just colour, they're multispectral. These scanners capture the scene in red, green and blue so they can produce a natural colour image, and they also work in one or more infrared bands.

A minimum of four and sometimes up to eight spectral bands are recorded and any three can be selected and combined into a false colour image. By selecting different combinations of the spectral bands, particular

geological or biological features can be identified in the image.

The ultimate is the hyper-spectral scanner, where the image is recorded in lots of narrow spectral bands, sometimes a hundred or more,



and it's still used onboard Landsat and some of NASA's other satellites. The diagram at the top of this page shows a panchromatic scanner, the name that imaging experts use to describe a monochrome scanner. However, the principle of a



By combining visible and infrared to create a false colour image, features not otherwise visible can be seen clearly

ranging from the visible, through the near infrared, to the far infrared portions of the spectrum. Hyper-spectral scanners are still a rarity due, in part, to the difficulty of processing such a vast volume of data.

Multispectral scanners use beam splitters to illuminate multiple sensors in a whiskbroom scanner or beam spreaders to illuminate multiple parallel linear CCDs in a pushbroom scanner. Each photo sensor or CCD is covered with a filter to make it sensitive to one spectral band only. Hyper-spectral scanners work differently, using a diffraction grating to split up the light like a prism so that light from different parts of the spectrum falls on different sensors or CCDs.

Although silicon-based CCDs like those used in ordinary digital cameras are used for imaging in the visible spectrum, other materials such as Indium-Antimony or Cadmium-Mercury-Tellurium are used to provide the necessary sensitivity to infrared radiation. What's more, because sensors for the medium and far infrared have to be cooled to a few degrees Kelvin, they are mounted separately from the other sensors on a 'cold focal plane'.

IMAGE PROCESSING

Image processing is often the icing on the cake in ordinary digital photography. With satellite imaging the raw photograph needs a lot of additional processing before an image can be used for any practical application. This falls into two categories: geometric correction and radiometric correction.

The main sources of geometric error are the Earth's rotation and curvature. The Earth rotates from west to east, but imaging satellites orbit the Earth from pole to pole. This means that the path of the satellite on the Earth's surface forms a series of S-curves instead of straight strips and a series of successive scan lines doesn't form a rectangle on the surface of the Earth. The most basic steps in the geometric correction of an image involve using mathematical transformations to correct this error and also the error caused by the Earth's curvature.

However, other factors – most notably slight variations in the satellite's altitude and velocity – also play a part in distorting the image. Because these errors are unpredictable, a fixed formula can't be used to correct them. Instead, we rely on ground control points. Here, the image is transformed so

that a series of accurately surveyed points on the Earth's surface – often road intersections – align with those same points in the image. This is equivalent to deforming a flexible transparent film image until it aligns with junctions on a map.

The data transmitted to Earth from an imaging satellite is a sequence of digital values outputted by the scanner's electrical sensors or CCDs. Usually, these values are referred to as Digital Numbers or DNs. For an image to be useful, values for the reflectivity of the Earth's surface are needed and, unfortunately, the DNs are subject to a number of other influences, which must be accounted for and corrected.

The most severe form of radiometric error is the total loss of an image line due to a glitch in the scanner or a dead pixel on the CCD. Single lost scan lines can be estimated by averaging the pixels in the scan lines either side of the missing line. Multiple lost lines are filled in by a combination of repeating and averaging neighbouring scan lines.

The other major type of correction to compensate for deficiencies in the scanner is called detector normalisation. This applies only to pushbroom scanners. Individual elements of a CCD nearly always have slightly different sensitivities to light. This is true of an ordinary digital camera, but here the slight differences are barely noticeable because they're scattered around a two-dimensional array.

With a pushbroom scanner, the use of a linear array means that the same differences will apply to every scan line, producing visible striping in the final image. To correct this, a scaling factor is applied to the output of each of the CCD's sensors using calibration data acquired in the laboratory as part of the scanner setup procedure.

Once these corrections have been carried out, the data should represent the amount of light received at the satellite for each point on the Earth's surface. But even this isn't the same as the reflectivity of those same points. The amount of light arriving at the satellite also depends on the angle of the sun in the sky (which affects the amount of atmospheric absorption of sunlight reaching the Earth), the satellite's viewing angle (which affects the amount of light absorbed in the atmosphere between the Earth and the scanner) and the effects of atmospheric haze. Errors due to illumination and viewing angles are easily corrected ☺

SATELLITE IMAGES ON THE WEB

Want to see what your home town, favourite holiday destination or a newsworthy location looks like from space? Buying full-resolution satellite images from one of the commercial satellite operators will cost you an arm and a leg, but you'll be able to find a lower-resolution version online free of charge.

The www.terraserver.com website lets you search by place name or by latitude and longitude and then pick a satellite or aircraft. Imagery is available from various satellites, including DigitalGlobe's QuickBird, Spin-2, Earthsat, Orbimage's OrbView, Landsat and other NASA satellites. You can freely view any scene at a resolution of up to eight metres per pixel. If you subscribe (from \$9.95, around £5.50, for seven days), you can view it at the highest resolution available for the satellite of your choice. Once you've viewed it onscreen you can purchase a print or a poster, or pay to download the image file.

Alternatively, check out the high-resolution images of famous landmarks in the Sample Imagery page at www.digitalglobe.com.

Navigation Help
Purchase Help
Measurement Help

Resolution: 8 Meter
Lat: 51.682763
Long: -0.128172
Image Size: 4,000 meters x 4,000 meters
Nearest City:

Date Taken: 12/16/2003
Best Resolution: 0.122 Meter

Parc:
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Zoom In/Out
Quick Zoom

Quick Pan

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\$69.95 - 3XL (32768x32768) pix

Print Sizes:
\$21.95 - 8" x 8" Glossy Print
\$21.95 - 8" x 10" Glossy Print
\$26.95 - 10" x 10" Glossy Print
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\$31.95 - 11" x 14" Glossy Print
\$31.95 - 11" x 17" Glossy Print
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\$59.95 - 16" x 20" Laminated F
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\$79.95 - 20" x 20" Laminated F

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using scaling factors, but correction for scattering due to haze is more difficult. The best methods need additional measurements of the amount of water vapour, gases and particles in the atmosphere, and this data isn't often available.

However, there are other workarounds that don't rely on the availability of this data. Some are just a form of contrast enhancement working on the assumption that the darkest pixel in any image should actually be fully black but has been artificially lightened by atmospheric scattering. Other methods, which are available only for multispectral scanners, use data from the infrared bands, where scattering is less pronounced, to remove any haze from the visible images.

NOWHERE TO HIDE

When we bear in mind the technology embodied in the scanners and the sophistication of the software used to process the raw data, the 610mm resolution of DigitalGlobe's QuickBird satellite might not sound so unbelievable after all. But if industry experts are to be believed, this pales into insignificance in comparison to some of today's less well-known satellites. That first Corona spy satellite had a resolution of eight metres per pixel, yet the first publicly released images published 12 years later from NASA's Landsat-1 achieved just 80m. Today's commercial satellites, mostly operated by American companies, require a licence from the US government. That licence limits the image resolution. If the resolution of QuickBird is the highest the US government will allow, we can only speculate on what today's state-of-the-art spy satellites can achieve. 

APPLICATIONS OF SATELLITE IMAGERY

Being able to view your own home by satellite is fun, but catering for idle curiosity wouldn't justify the existence of a multi-billion pound industry. So who uses satellite imagery and why? To find out we spoke to Clark Nelson, sales and marketing manager of Spot Image Corporation, the American subsidiary of the French company that operates three SPOT satellites.

The military put the first imaging satellites into orbit and defence organisations are still the main users. "If they're going into a part of the world for humanitarian relief or offensive operations, they need to know what it looks like," said Nelson. "Satellite imaging is best because maps are invariably out of date. What's needed is a dynamic method of observation".

Another important application is agriculture. At one end of the spectrum, Nelson explained how satellite imaging is being used to help reduce famine. At the other end it's being used by traders in the crop futures commodity market.

Satellite images also play a vital role in mining and mineral extraction. We asked Nelson how satellite images help in oil exploration. "Initially, it's used to see where oil might be located from observing surface indications", he explained. "If a company can look at an image before sending staff into the field they're well ahead of the game". Nelson



The colours in this image of Thessaly plain, Greece, highlight different stages of growth in cotton fields. The image makes it easier to assess crop maturity and variations for estimating yields and devising an effective production management strategy

went on to explain how oil companies also use satellite imagery to plan infrastructure; where to place the wells, where to build roads and which way to route the pipelines.

One of the biggest potential applications of satellite images is still in its infancy. Terraserver makes images available to the public, and mapping sites such as Streetmap (www.streetmap.co.uk) let you see images of certain parts of the country (though taken from an aircraft rather than a satellite) in addition to a conventional map. According to Nelson, this is just the tip of the iceberg. "In the future we'll see images used as a general background to anything we're doing that's concerned with maps or geography."

PHOTOGRAPHY: © CNES 2002 DISTRIBUTION SPOT IMAGE

CRISIS MANAGEMENT: SATELLITE IMAGES AND THE TSUNAMI

December's tsunami was one of the worst natural disasters ever, but had it not been for the photographs acquired by DigitalGlobe's QuickBird satellites, the death toll could have been even greater.

Work carried out by the Immersive Visualization Center (VizCenter) at San Diego State University was key to the relief effort in Banda Aceh, one of the worst affected areas of Indonesia. The centre was one of the first to receive satellite imagery of the area. By comparing before and after images, the latter acquired by QuickBird just two days after the disaster, the scale of the devastation – showing damage to the coastline, buildings, vegetation and roads – was obvious. "The immediate availability of DigitalGlobe's dramatic imagery helped the world truly understand the damage and the death tolls. The images motivated people to take immediate action and send relief to south-east Asia," said John Graham, a senior research scientist at the VizCenter.

But the use of this imagery went well beyond education and motivation. It was also used to help establish refugee camps and provide much-needed medical assistance. In early January, two medical doctors from the VizCenter flew to Indonesia to work with the US military, NGOs and the United Nations to assess the scale of the damage and determine where to build refugee camps, medical facilities, communications networks and transportation



Before and after shots of the area devastated by the tsunami were essential in coordinating the relief effort

routes. The preliminary work involved writing special software to make quick comparisons of before and after shots, creating 3D fly-throughs, and making the images available on a secure server hosted at the San Diego Supercomputer Center for access by relief workers and decision makers.

"The imagery has been invaluable for working with city and village leaders and

making rapid decisions. The ultra-fast urban planning these images enables will have long-term impacts on the Acehnese people and their way of life," said Eric Frost, codirector of the VizCenter. "We are also working with Indonesian partners such as the University of Gadjah Mada, which take our imagery and link to the Indonesian disaster officials and local NGOs who can most effectively use the data."

PHOTOGRAPHY: DIGITAL GLOBE